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(54) **Light emitting diode array devices and image transfer systems**

(57) A light emitting device comprises a substrate (12); a first chip (14) incorporating a high density of light-emitting diodes (16), e.g. at up to 1000/inch, arranged in a substantially linear array and with electrical contacts (18), preferably extending alternately to opposite sides of the row; and one or a pair of IC chips (24) incorporating RAM and drivers for the diodes. The IC chips (24) are positioned alongside the LED chip (14) and interconnections are made by very fine wires (28) ultrasonically bonded to the contacts (22,26). The hybrid circuit modules (10, 10*a*) can be assembled side by side to give an extended diode array. The device (10) is utilised in image transfer systems where the diodes output to fibre optic filaments, micro-lenses or the like closely spaced above the diode chip (14) and having their output at or adjacent to a photo-sensitive medium. The system is particularly useful for high-speed, high-resolution phototypesetting.

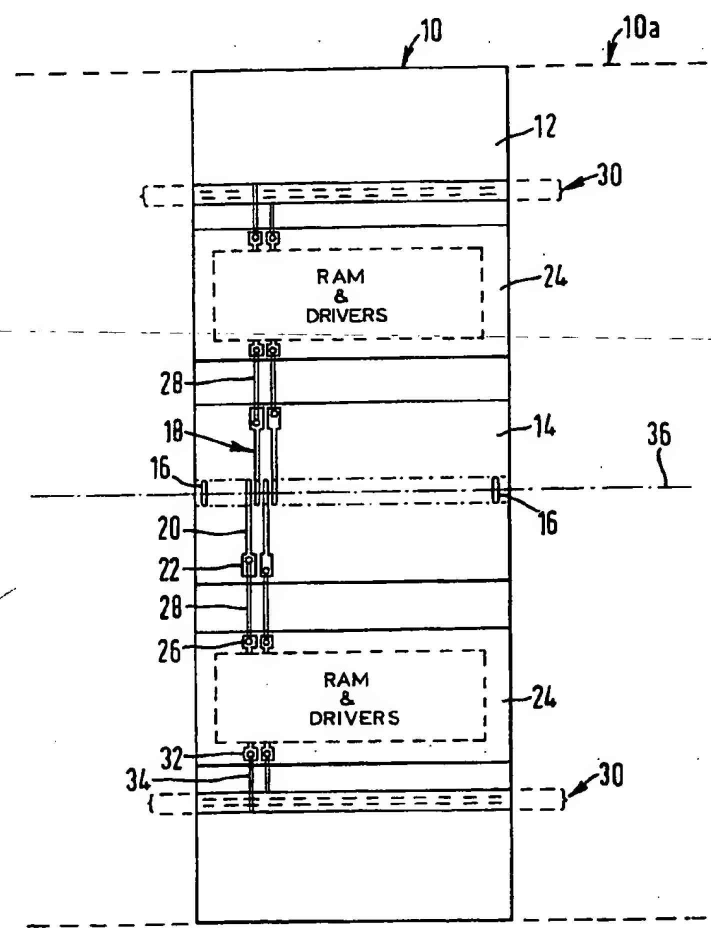

FIG. 1

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The drawing(s) originally filed were informal and the print here reproduced is taken from a later filed formal copy.

SPECIFICATION

Light emitting diode array devices and image transfer systems

Field of the invention

This invention relates generally to light emitting diode array devices, particularly in the form of hybrid integrated circuit modules, and to ways of utilising these devices, particularly in image transfer systems. The light emitting diode array devices of the present invention are especially appropriate to provide a display when can be transferred to expose a photosensitive recording surface, such as a film or paper, or alternatively a photocopying receptor such as a selenium drum or zinc oxide paper. Using the light emitting light array devices of the present invention in an image transfer system one can achieve a high speed, high resolution optical printer. The invention also has application to high speed, high resolution photo-type-setting, and, at lower resolutions, intelligent copiers, plotters and similar devices having a graphics output.

Background of the invention

Visual display devices incorporating light emitting diodes as electroluminescent elements, such as gallium-arsenide-phosphide light emitting diodes are well known. Generally speaking these visual display devices are divided into two types, hybrid devices and monolithic devices. In the monolithic type of device, the light emitting diodes are formed in a semiconductor crystal substrate, for example by using etching techniques. In the known hybrid type device, a number of light emitting diode chips are mounted on a single substrate.

One of the problems of achieving very high resolution is that a very large number of light emitting diodes are required, positioned very close together. If the light emitting diodes are to be individually accessed so that each can be selected separately, then the control logic and connecting circuitry for addressing each diode becomes complex.

One attempt to overcome these problems is described in US patent specification 3701123 which describes a hybrid integrated circuit module in which display elements are disposed in one plane, and the logic for controlling the display elements is an integrated circuit disposed in another plane perpendicular to the display plane. A plurality of these modules are designed to be stacked side-by-side to produce rows and columns of display elements in a two-dimensional array. In this known arrangement the individual diodes are spaced so as to achieve about 40 diodes per inch at the maximum.

US patent No. 3947840 describes a visual display device comprising light emitting diodes having associated memory and drive circuits, in which the diodes are etched into the reverse side of a monolithic transparent planar substrate with the diodes and associated electronics being developed on the rear face of the substrate. Here again, this known arrangement is concerned with the scanning of rows and columns of diodes and the individual diodes have a centre-to-centre spacing of the order of 45 mil.

US patent No. 3914786 is again concerned with light emitting diode display devices and indicates therein that very small LED devices are often desired in order to reduce the distance between the centres of adjacent elements in an array. In this known patent diode devices of the order of 0.100 inch diameter are considered very small.

An inhibition on the production of extremely fine arrays of light emitting diodes (such as 500 per inch, or finer) has been that the requirement to connect the diodes to the driving sources implies the use of a separately manufactured circuit, produced on another substrate. This is because different structural arrangements are necessary for LED circuits on the one hand and driving circuits on the other hand. Furthermore, because of imperfections of processing materials, the yield of small luminescent elements is necessarily only a fraction of that which is theoretically possible.

Summary of the invention

It is an object of the present invention to provide a light emitting diode display device which is concerned, not with a block of elements arranged in rows and columns, but with a substantially linear array of emitting elements.

It is another object of the present invention to provide a light emitting diode display device in which the number of diodes in the array is of the order of hundreds of elements per inch, and indeed as much as 1000 elements per inch.

It is a further object of the invention to provide a method of making a light emitting diode array device in which individual LED chips are connected in an effective manner to associated driver chips which drive the LEDs.

It is yet a further object of the present invention to provide various types of image transfer system, based on the use of the aforesaid LED array, which enables the light emitted by the individual diodes to be transmitted with high efficiency to a sensitive recording surface.

In order to achieve these objects, and in order to overcome the aforementioned difficulties the light emitting diode array devices of the present invention make use of a hybrid circuit module which integrates the successful and tested yield of a first production process which produces an LED chip, and a second production process which produces a chip consisting of random access memory and LED driving circuits.

It is a further object of the present invention to provide light emitting diode array devices which can be manufactured in relatively short unit length, and which can be assembled in a linear manner, for example for the purpose of paper marking, into arrays of appropriate lengths to match particular widths of printed output pages. For example, it is envisaged that assembled arrays 200 mm or more in total length could be used.

In accordance with one aspect of the present invention there is provided a light emitting device comprising a substrate, a first chip mounted on the

substrate and provided with a pluerality of light emitting diodes arranged in a substantially linear array and with individual first contact means associated with each diode extending to one side of the diode array, a second chip mounted on the substrate spaced from and at said one side of said first chip and provided with accessible memory and driving means for said diodes and with individual second contact means, and means connecting each of said first contact means to said second contact means.

In accordance with another aspect of the present invention there is provided a light emitting device comprising a substrate, a first chip mounted on the substrate and provided with a plurality of light emitting diodes arranged in a substantially linear array and with individual first contact means associated with each diode extending alternately to one side and to the other side of the diode array, a pair of second chips mounted on the substrate spaced from and respectively at said one side and at said other side of said first chip and each provided with half the total accessible memory and driving means for said diodes and with individual second contact means, and means connecting each of said first contact means to one of said second contact means.

Preferably, the first contact means are aligned with said second contact means and said connecting means comprises individual wires bonded to said respective contact means.

The arrangement in which two memory/driver chips are arranged one on each side of the diode chip has particular advantages. The diode chip contact means, which are electrically connected to the diode electrodes, and which have of necessity to be insulated from one another, are made more effective by bringing out alternate contact means, i.e., leads, to opposite sides of a centre line. For example, this enables each individual contact means of the diode chip to be made larger than the active emitting area of the individual diodes, whilst additionally maintaining an improved insulating gap. This technique, in which the driving circuits are placed independently on both sides of the centre line which defines the luminescent elements considerably improves the yield. A further advantage is that the "half-sized" driving circuits benefit from a disproportionately increased yield.

These and other advantages apply whether the diodes are placed in a single straight-line high density array, or in a staggered row with alternate diodes offset to one side and to the other side of a central axis. In the latter case, more complex memory may be necessary in order to compensate for the displacement.

Preferably, each of the first and second chips is of substantially the same thickness, whereby the upper surfaces of the chips lie substantially in a common plane. This simplifies the interconnections between the diode chip and the IC chip or chips, and also ensures optimum thermal impedance.

In conventional scanning techniques it is usual for the incoming signal to be used to modulate the resolvable areas synchronously, i.e. the signal sequentially scans and activates adjacent areas of active material, each area being only briefly exposed to the signal for a short cycle time which is directly proportional to the length of the total line beam scan. Thus, in an 8 inch line having 8000 resolvable areas, each one would be processed for one unit time in every 8000.

It is a preferred feature of the light emitting device of the present invention that each active luminescent element, i.e. diode, has associated therewith a latch, or memory device, such that this proportion can be increased to a one-to-one ratio, for example from one part in 8000 to 8000 in 8000, thus eliminating the requirement to have an elevated energy capability.

Additionally, because the diodes are latched on or off, the electronic scan rate need not be rigidly synchronised with the line displacement mechanism. Elimination of this rigid electro-mechanical synchrony renders the device of the present invention, and its operation, more practical and economic.

A further advantage of incorporating a latch associated with each elemental area of the diode array is that simultaneous entry can be achieved at several places within the line, and as desired, in order to improve apparent bandwidth limitations. In dealing with a line of type, similarly shaped symbols can be addressed simultaneously from a character generator, even if they are displaced irregularly. The multiple entry points can be regularly or irregularly spaced, or in mixed mode within a line, and not necessarily sequentially scanned.

According to a preferred feature of the invention, the light emitting device comprises a plurality of modules each comprising a substrate and first and second interconnected chips, the width of each substrate being equal to the length of the diode array carried thereby, and the modules being assembled in side-by-side abutting contact to provide an extended continuous linear diode array.

According to another aspect of the present imnvention there is provided an image transfer system comprising a light emitting device of the type referred to above, in combination with light-transmitting means having an input end fixedly mounted to receive light from said diode array and an output end remote from said input end.

The light-transmitting means may comprise an array of fibre optic filaments, or a linear array of microlenses for example.

The present invention also includes a method of making a light emitting device of the type referred to above, which comprises the steps of mounting the first chip on a substrate with the length dimension of the diode array across the width of the substrate, mounting the or each second chip alongside the first chip, and ultrasonically bonding individual connecting wires between each of said first contact means and a respective one of said second contact means.

In order that the invention may be fully understood, various embodiments in accordance with the invention will now be described by way of example and with reference to the accompanying drawings, in which:

Figure 1 is a schematic plan view of a light emitting diode array device in accordance with the present invention;

Figure 2 is an illustration of an altemative way in

which the individual diodes can be arranged in a row;

Figure 3 is a schematic side elevation illustrating the use of the device of Figure 1 in a first embodiment of image transfer system in accordance with the invention;

Figure 4 is a schematic view, similar to Figure 3, but showing an alternative image transfer device; and,

Figure 5 is a view, similar to Figure 4, but showing yet another alternative image transfer device.

Referring first to Figure 1, this shows the light emitting device of the present invention indicated generally at 10. The device 10 is constructed as a hybrid circuit module comprising a number of chips mounted on a ceramic substrate 12. The module is rectangular in plan view. A first chip 14 (hereinafter referred to as the LED chip) is positioned centrally on the substrate 12, for example by gluing with the chip exactly at right-angles to the longer sides of the substrate. The individual light emitting diodes are indicated at 16 and have their active luminescent faces at the upper surface of the chip. The individual diodes 16 are spaced from each other, but are provided at extremely high densities in terms of numbers of diodes per unit length of the chip. Linear arrays of diodes have been produced successfully at densities of between 300 and 600 diodes per inch, achieving good yields on yellow and red emitting materials in particular. With diodes emitting in the red, i.e. at about 655 nm, and with active areas at 49 μ pich, densities of the order of 1000 diodes per inch have been achieved with good yields. In practice, it is convenient to make each module 10 approximately 1/8th inch long, with the ends of the diode chips 14 and the longer edges of the substrate 10 being finely ground to permit the assembly of a plurality of such modules side-by-side to build up a continuous extended linear diode array. One such additional module is indicated in broken lines at 10*a* in Figure 1.

It is convenient for example to produce a diode chip 14 having a linear array of LED elements 16 with the chip machine sawn so as to be precisely 0.128 inches in length (or 0.256 inch or another such preferred dimension related to acceptable yields) while carrying the appropriate number of separate whole diode elements, i.e. 128 elements in a length of 0.128 inches. It is emphasized that the particular dimensions and densities referred to herein are given by way of example only. As mentioned above, the ceramic substrate 12 has a width exactly equal to the selected width of the LED chip 14, but has its other dimension nominal. This latter dimension is chosen so as to provide a conveniently sized support for connections, clamping means, etc.

The LED chip 14 is provided with contact means indicated generally at 18, and associated one with each diode element 16. These contacts or leads 18 are for example of aluminium, laid down on the chip by a suitable masking technique. As an alternative to aluminium, gold may be used as the contact material. Each contact 18 is connected at one end to one of the diode electrodes, the other diode electrode being connected to external circuitry (not shown). Each contact 18 comprises a relatively narrow finger portion 20 which, towards the sides of the chip, is enlarged to form a relatively wide plate portion 22. As shown in Figure 1, the contacts 18 extend alternately towards one side and towards the other side of the chip, from the individual diodes 16. This has advantages, as described above, particularly at the extremely high densities used.

On each side of the LED chip 14, on the flat top surface of the substrate 12, there is mounted an IC chip 24, fabricated quite separately from the LED chip 14. Each IC chip 24 has the same width as that of the LED chip 14 and is glued for example to the surface of the substrate. Each IC chip 24 consists of a 64 × 1 bit static random access memory and 64 constant current LED drivers; each memory bit can be accessed through 6 address bits, chip enable and read/write signals. There are two data pins, data in and data out. Data out has the same polarity as the input data and its output driver is a constant current LED driver. The 64 bits of RAM also output in parallel, and each output drives a constant current LED driver. An external reference voltage is used to adjust the current through the drivers. This external voltage can in turn be adjusted by varying the value of external resistors. The height of the chip is less than 128 mils and is fabricated with N-channel silicon gate technology.

It will be appreciated that for a total of 128 diode elements 16, each of the chips 24 bears half the number of active memories related to the referred LED number, i.e. 64 memories for 128 LEDs. A special feature of the memory/driver chips 24 is that, whereas it is common practice to construct the elemental memory cells so as to have low energy capabilities, and subsequently amplify any such cell or cells but not normally all to a useful energy only when being electrically "read", the present arrangement provides that each memory bit shall be strong enough to drive one LED element directly.

The driving outputs of the IC chips 24 are again formed as contacts 26, for example of aluminium or gold, and these contacts 26 are disposed linearly with the same spacing as the facing contacts 18 extending to the side of the centrally positioned diode chip 14.

An important feature of the present invention is the connection of the diode contacts 18 with the driver contacts 26. Preferably, the connection between the pairs of contacts is effected by the use of extremely thin wire, for example aluminium or gold wire, connected at each end to the respective contact plates. These connecting wires are indicated at 28. The wires 28, although extremely fine, are also relatively short because the IC chips 24 are positioned relatively close to the LED chip 14. The wires 28 therefore have a substantial degree of inherent rigidity because of their short length. The connection between each wire end and the associated contact plate is preferably effected by ultrasonic bonding. This involves placing the wire end in contact with the contact plate and subjecting the wire to ultrasonic vibration which effects the bonding between the wire and the plate. As is illustrated in Figure 1, it is desirable for the bonding of the wires to alternate contact plates 22 or 26 to be effected in a staggered

manner, in order to minimise the danger of bridging the gaps between the contacts.

The wires 28 may be encapsulated, for example in a resin paste which is cured, in order to increase the stability of the connections and to permit mechanical handling of the device. This encapsulation may be particularly necessary if the wires 28 are relatively long.

Alternative ways of making interconnections between the respective contacts may be used. For example, in one alternative method, the chips are mounted on the substrate, the chips are then masked so as to leave the contact areas exposed, a metal is deposited over the exposed contact areas so as to short all the connectors together, and the, where gaps existed between adjacent contacts prior to the shorting process, these are re-established and extended across the bridged gap by means of a laser-trimming device, as is known in the art.

Each random access memory in the chips 24 is addressed by means of an on-board address decoding circuit, as is common to random access memories. For an array of 128 latched memories this would necessitate 7 addressing wires, plus a data wire which signifies whether the addressed memory should be energised or not, plus an overall clock wire so as to synchronise multiple memory operation. These addressing and data wires, which are indicated generally at 30 in Figure 1, together with the necessary two power wires, are brought out on the side of each chip 24 opposite to the side adjacent to the LED chip 14. Further contact plates 32 along the edge of the chips 24 are connected by bonded wires 34 to the address/data wires 30. When a number of such modules 10, 10a, etc. are assembled side-by-side in abutting contact to make an extended array, it is then only necessary to parallel up the aforesaid address wires, data wires, clock wires, etc.

It should be understood that although in the preferred embodiment illustrated in Figure 1 a memory/driver chip 24 is provided at each side of the LED chip 14, one could alternatively use just one memory/driver chip 24 with twice the memory and driver capacity, and with all the contacts from the diodes 16 then extending to one side of the LED chip 14. This arrangement could be practical at lower densities of diode elements.

It is also advantageous if the thickness of all the chips is substantially the same, not only to simplify the interconnections through the wires 28, but also to create conditions for optimum thermal impedance.

Figure 2 shows one alternative way of arranging the diode elements 16 in a row so as still to achieve the benefits of the substantially linear array. In this embodiment the diodes 16 are alternately offset to one side and to the other side of the longitudinal axis 23 of the diode array.

As mentioned above, the light emitting device of the present invention is designed for use as part of an image transfer system whereby a light image is transmitted to a photosensitive surface. In order for the LED array to produce intelligible "printed" output in a conventional sense, it is clear that any composite image which may be energised, however it is made visible, has to be mechanically displaced in a direction at right-angles to the longitudinal axis 36 of the array. This may be achieved by intermittent displacements, or by the continuous movement of an image-carrying medium.

It will be appreciated that in the case of imperfect continuous motion the resulting image (for example a solid one) will vary only in local density, whereas an image scanned by a laser or a CRT beam would show a gap, or perhaps a (less noticeable) overlap between successive scan lines.

When any or all of the LEDs in the array are energised, the effect of movement of a recording material across them is to produce adjacent and parallel stripes, the length of which can be determined by measuring the movement of the material across them and selectively switching the LEDs to construct elementally any pattern or combination of separate patterns, such as high resolution typographic images in elemental construction appropriate to different point sizes.

In an image transfer system incorporating the aforesaid modules it is necessary to combine the modules with suitable image transfer means in order to enable faithful recording, without edge fall-off commonly found in conventional optical systems, on the photosensitive sheet material or on an indirect image record carrier. Such image transfer means can be combined with the LED modules in appropriate systems during manufacture.

Figure 3 shows one embodiment of image transfer system. A linear array of fibre optic filaments 40 is positioned above the light-emitting LED chip 14. The fibre optic array comprises large numbers of fibres, for example of 6μ diameter, so that a bundle of fibres is associated with each diode. This improves the resolution. The length of the fibre array is of course equal to the length of the diode array and the fibre array is mounted between two supports 42, 43 which sandwich the fibres between them and mount them fixedly relative to the diodes. The supports 42, 43 may be glass plates for example. The bottom of the fibre array projects slightly below the bottom of the supports 42, 43, and the bottom of the fibres, i.e. their input ends, are arranged to be in very close proximity to the diodes. The other, i.e. output, ends of the fibres are flush or slightly below the top surface of the supports 42, 43, over which a photosensitive paper or film 44 is arranged to pass in the direction indicated by the arrow 45. Depending primarily upon the photosensitive material used, the output ends of the fibres may either be in close proximity to or actually in contact with the surface of the photosensitive material. The photosensitive material may be for example zinc oxide paper, suitable for "dry" development, or photographic emulsion on film or paper, normally requiring "wet" development.

In an alternative embodiment as shown in Figure 4, where a selenium drum 50 serves as an intermediate transfer medium to the final record medium (typically toner-carrying plain paper), the drum because of its limited life and rigid surface is unsuitable for intimate contact with the rigid surface of a knife-like fibre-optic array. The required high resolu-

tion image transfer is here achieved by substituting for the fibre-optic device of Figure 3 a linear arrangement of micro-lenses 52, such as are manufactured by the Nippon Sheet Glass Company under the trade name "Selfoc". This micro-lens array 52 is placed so as to be at a fixed separation, typically one quarter-inch, from the relatively fragile emitting surfaces of the LEDs, with similarly a one quarter-inch spacing between the other end of the micro-lens array and the surface of the selenium drum 50. This arrangement of necessity reduces the amount of light transmitted, although such an array may have a transmission value equivalent to f1.0. By suitably lowering the speed of recording medium displacement, the loss in energy can be compensated.

The conjugate distance of the micro-lenses, in the manufactured form previously referred to, is such that mechanical adjustments such as focussing are unnecessary, and adjustment-free pre-machining of the mounting means is a practical feature.

As a further option, and as shown in Figure 5, in such cases where the energy level required is not excessive, for example where an f1.0 transmission value is adequate, the above-described arrangement can be made suitable for direct recording on to flexible carriers, such as zinc oxide or photographic paper, with appropriate speed compensation, and without removing the drum, by replacing the knife-like optical fibre array with a micro-lens array 52 to which is added a removable optical glass 54. When such an optical glass 54 is inserted between the drum 50 and the micro-lens array 52, the focal length of the micro-lens array is foreshortened by about one third, thus enabling photo-sensitive material to travel in immediate contact with the surface 56 of the optical glass, accepting the high resolution image in the manner of and with the convenience of the previously described contact method. The glass surface 56 should have suitable curvature so that the "feed on" and "feed off" of the recording material, being closer than the focussed image, ensures suitable contact.

It should be noted that where for some reason the surface 56 cannot be allowed to be curved, a pressure pad may optionally be introduced.

It should be understood that the illustrations of the various components and elements in the drawings are not shown to scale or even in their correct relative sizes. The intention of the drawings is to illustrate the various important features of the invention.

CLAIMS

1. A light emitting device comprising a substrate, a first chip mounted on the substrate and provided with a plurality of light emitting diodes arranged in a substantially linear array and with individual first contact means associated with each diode extending to one side of the diode array, a second chip mounted on the substrate spaced from and at said one side of said first chip and provided with accessible memory and driving means for said diodes and with individual second contact means, and means connecting each of said first contact means to said second contact means.

2. A light emitting device comprising a substrate, a first chip mounted on the substrate and provided with a plurality of light emitting diodes arranged in a substantially linear array and with individual first contact means associated with each diode extending alternately to one side and to the other side of the diode array, a pair of second chips mounted on the substrate spaced from and respectively at said one side and at said other side of said first chip and each provided with half the total accessible memory and driving means for said diodes and with individual second contact means, and means connecting each of said first contact means to one of said second contact means.

3. A device according to claim 1 or 2, in which said first contact means are aligned with said second contact means and said connecting means comprises individual wires bonded to said respective contact means.

4. A device according to claim 3, in which the wires are encapsulated.

5. A device according to any preceding claim, in which each of said first contact means comprises a relatively narrow finger of electrically conductive material extending from the diode and a relatively wider plate of the same material to which said connecting means is fixed.

6. A device according to any preceding claim, in which at least said first contact means and said connecting means are of aluminium.

7. A device according to any preceding claim, in which the array of diodes is a staggered row with alternate diodes offset to one side and to the other side of a central axis.

8. A device according to any preceding claim, in which each of said first and second chips is of substantially the same thickness whereby the upper surfaces of the chips lie substantially in a common plane.

9. A device according to any preceding claim, in which said accessible memory and driving means comprises individual memory means and latch means for each diode whereby each diode or any group of diodes may be addressed without regard to the sequence of diodes in the array.

10. A device according to claim 9, in which the addressing and data wires for the or each second chip are brought out from the chip on the side thereof opposite to the side from which said second contact means extend towards the first chip.

11. A device according to any preceding claim, comprising a plurality of modules, each comprising a substrate and first and second interconnected chips, the width of each substrate being equal to the length of the diode array carried thereby, and the modules being assembled in side-by-side abutting contact to provide an extended continuous linear diode array.

12. An image transfer system comprising a light emitting device as claimed in any preceding claim, and light-transmitting means having an input end fixedly mounted to receive light from said diode array and an output end remote from said input end.

13. An image transfer system according to claim 12, in which said light-transmitting means comprises an array of fibre optic filaments mounted between supports to give the array rigidity, the length of the filament array being equal to the length of the diode array.

14. An image transfer system according to claim 13, in which the lower end of the filament array projects down below said supports into close proximity to the active surface of the diode array.

15. An image transfer system according to claim 12, in which said light-transmitting means comprises a linear array of micro-lenses.

16. An image transfer system according to claim 15, which includes an optical glass element between the output end of the micro-lenses and a photosensitive recording medium, the recording medium travelling in contact with the surface of the glass element remote from the micro-lenses.

17. An image transfer system according to any of claims 12 to 16, in which the output end of the light-transmitting means is in direct contact with a photosensitive recording medium which is arranged to pass over the light-transmitting means at right-angles to the longitudinal axis of the diode array.

18. A method of making a light emitting device as claimed in any of claims 1 to 11, which comprises the steps of mounting said first chip on a substrate with the length dimension of the diode array across the width of the substrate, mounting the or each second chip alongside said first chip, and ultrasonically bonding individual connecting wires between each of said first contact means and a respective one of said second contact means.

19. A method as claimed in claim 18, which includes ultrasonically bonding further connecting wires between the or each second chip and further circuit means carried by the substrate.

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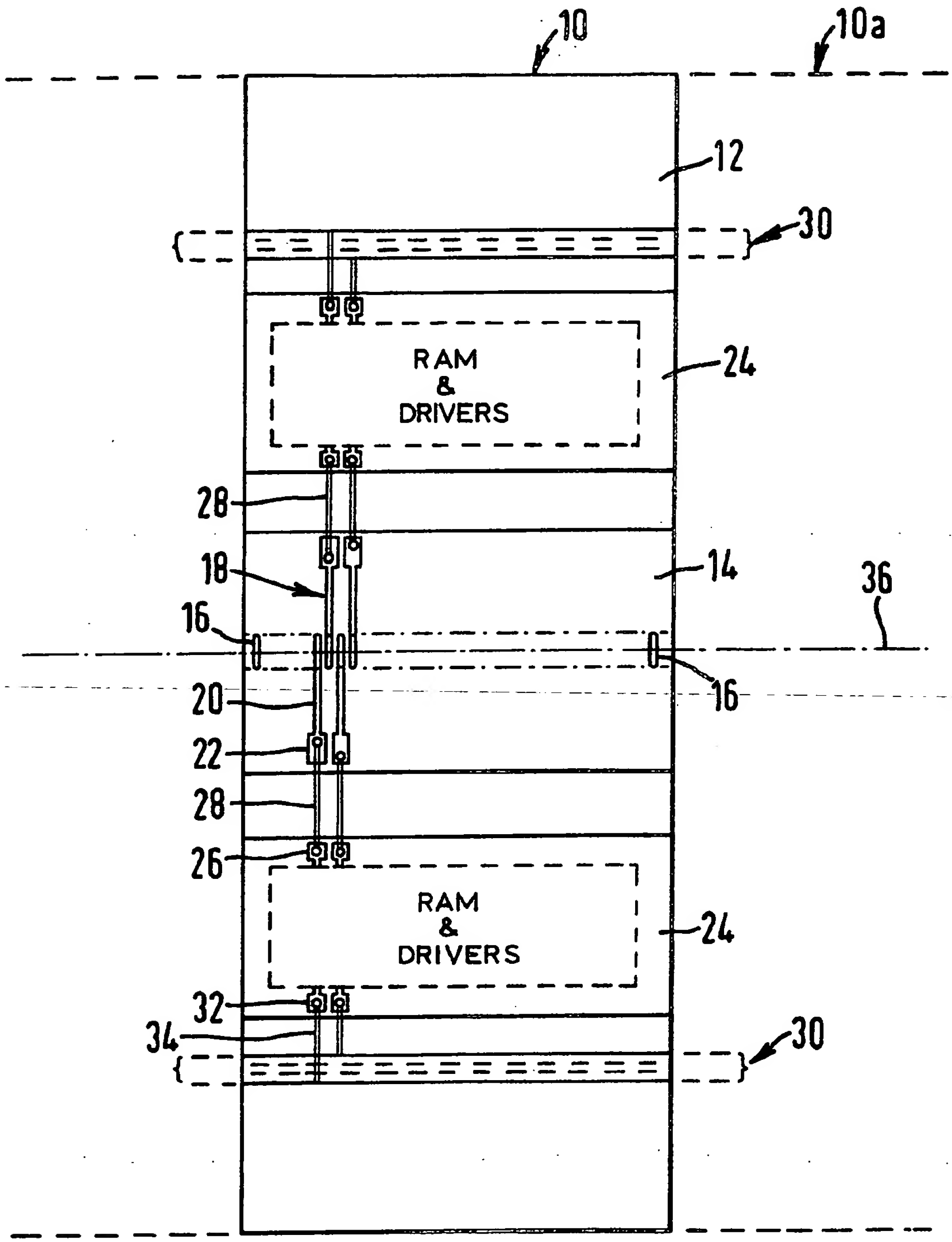

FIG.1

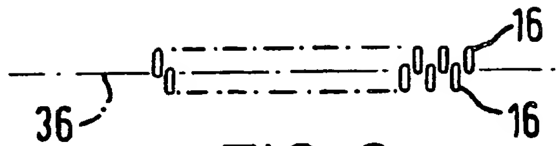

FIG. 2

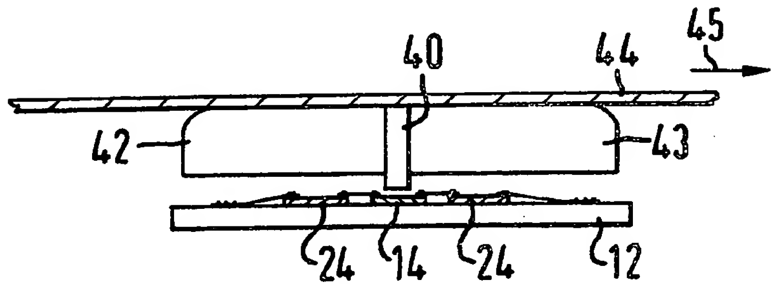

FIG. 3

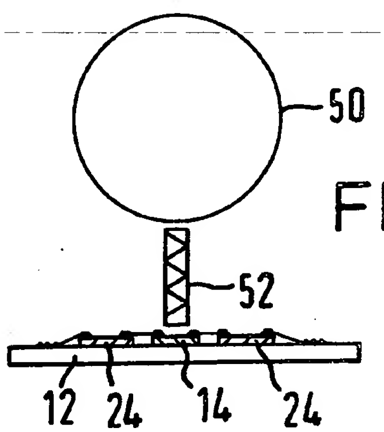

FIG. 4

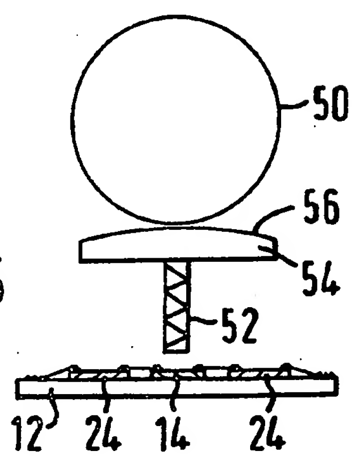

FIG. 5